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# EFFECT OF METEOROLOGY ON THE ATMOSPHERIC CONCENTRATIONS OF INDUSTRY- RELATED POLLUTANTS IN INDIA

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**ABSTRACT**

In the present study, the effect of meteorological parameters on different air pollutant concentrations has been analyzed using correlation analysis and graphical presentation in the surrounding area of a fertilizer plant located at Aonla, (U.P.) India, during the year 2015. The results of the study show that all the air quality parameters documented a negative linear interactions with maximum temperature ($R^2$ = 4.9 – 73.5%) and precipitation ($R^2$ = 0.04 – 26.0%). A significant positive linear interaction between relative humidity and all air pollutants ($R^2$ = 1.4 – 52.3% and $R^2$ = 0.08 – 47.5%), were also found. For all the apprehensive cases, the wind speed and evaporation were found to have considerably good linear interaction with all the air pollutants, signifying that the concentrations of pollutants from nearby areas tend to get diluted with increasing wind speed but may be elevated as the speed of wind decreases. On the basis of the results obtained, it can be concluded that differences on the atmospheric pollutants levels during the whole year into consideration can be attributed to the differences in meteorological conditions.

**KEY WORDS**
Pollutant concentrations
Meteorological parameters
Correlation
Regression analysis

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## INTRODUCTION

Air quality of a region is the result of a composite interaction between natural and anthropogenic environmental conditions (Banerjee, 2010) and keeping the air quality upto standard has become an important undertaking for government, decision makers as well as for non-governmental organizations. Particulate matter and gaseous emissions of pollutants from industries and auto exhausts are responsible for rising discomfort, increasing respiratory diseases and deterioration of surrounding environment (Anjaneyulu *et al*., 2005). Apart from rapid industrialization, urbanization has also resulted in the emergence of industrial centres without a corresponding increase in civic facilities and pollution control mechanisms. In Indian cities, the pollutants level are getting worse because of rapid industrialization, rising number of vehicles, energy consumption and burning of wastes.

Some pollutants emitted either by anthropogenic or natural sources diffuse in the atmospheric boundary layer by turbulent eddies related to both mechanical forces (wind shear) and thermal forces (buoyancy) (Banerjee, 2010). Dilution and dispersion of air pollutants are strongly influenced by meteorological conditions, especially by wind speed and direction, atmospheric stability and turbulence (Banerjee and Srivastava, 2011). Relationship between meteorological parameters and air pollutant sources and concentrations are being cited in many literatures (Hosseinibalam and Hejazi, 2012; Pearce *et al*., 2011; Cheng *et al*., 2007; Elminir, 2005; Ordonez *et al*., 2005; Beaver and Palazoglu, 2009; Mkoma and Mjemah, 2011), which plays an important role in the dispersion, transport, photochemical reactions and secondary pollutants formation, however in spite of the presence of a enormous literature, many aspects of the association between air pollutants and meteorology are still not clear (Pearce *et al*., 2011), like the interaction between various meteorological variables; the dependency of boundary layer height on surface temperature; the connection between surface temperature and radiation or the association between relative humidity and temperature, which make straightening out the effects of individual parameter a highly complex task (Habeebullah, 2013). Meteorological variables can affect the concentrations of air pollutant directly by affecting photochemical ozone formation or dispersing locally emitted pollutants or indirectly by affecting other meteorological parameters or affecting some pollutants which in turn affect other pollutants (Jacob and Winner, 2009). Furthermore, the effects of meteorological variables on the concentration of pollutants vary both temporally and spatially (Thompson *et al*., 2001; Baur *et al*., 2004; Schlink *et al*., 2006; Camalier *et al*., 2007; Pearce *et al*., 2011). One tentative approach used to address this problem is to perform dispersion experiments, in which the emission rate of a certain tracer is highly controlled and its concentrations are measured in the surroundings (Martin *et al*., 2010).

The development of a consistent depiction of environmental trends and conditions requires the collection of adequate data, statistical analysis and integration of the information and the prerequisite of comprehensive, precise and clear presentations (Andria *et al.*, 2008). Ambient air quality monitoring helps to measure the existing air quality, assess the effectiveness of a control plan or strategy, activate an emergency control, weigh up the exposure of population and also specify the need for future land use planning. Nayek *et al.* (2013), made an approach for making air pollution profile of the Santiniketan-Bolpur-Sriniketan triangle and selected 13 sites for measuring air pollution levels with respect to SPM, $PM_{10}$, $PM_{2.5}$, $SO_2$, $NO_2$, $O_3$ and CO and employed Box and Whisker plot technique for determining the variations in the concentrations of the parameters, which could provide an air pollution database to the government for better planning for future development of the area. Using the technological advancements, a huge amount of data about ambient air quality is generated and used to ascertain the quality of air and to govern suitable air pollution counteractive actions, wherever necessary. Such an endeavour helps to describe the air quality and reports the concentration of all pollutants with acceptable levels. Moreover, the availability of measured air pollution data helps to describe the temporal and spatial behaviour of all pollutant emissions along with the constant variations in pollution and meteorological conditions effect (Andria *et al.*, 2008).

Thus, in the present study, concentrations of different pollutants ($PM_{10}$, $PM_{2.5}$, $SO_2$, $NO_2$ and $NH_3$) were measured during 2015 at different locations around the fertilizer industry. The objective undertaken was to study the variability and predictability of air pollutant concentrations in a particular location or region, determined by studying different factors of prevailing meteorological conditions in that area. Inter-correlation of different pollutants and meteorological parameters was studied to provide a more comprehensive understanding of the current status of air pollution.

## MATERIALS AND METHODS

The present research was conducted in Aonla based plant of Indian Farmers Fertiliser Cooperative Limited (IFFCO), in the state of Uttar Pradesh, India. Geographically Aonla fertilizer complex is located at in the northern region of India and at longitude 28° 13′ 34.87" N and latitude 79° 14′ 50.63" E at an elevation of 165 m above mean sea level. The average annual temperature in the area is 25.1°C, with average annual rainfall is 1037 mm. Based on the topography and meteorological conditions of the pre-defined study region, primarily a five ambient air quality monitoring location was selected in the IFFCO-Aonla industrial unit, out of these five location, four were located around the industry area and the fifth one was located in the residential area.

For the monitoring of $NO_2$, $SO_2$, $NH_3$, $PM_{10}$ and $PM_{2.5}$, Respirable dust sampler (RDS APM 460BL, Envirotech, New Delhi, India) was used along with Thermo Electrically Cooled Gaseous Sampler (APM 411TE, Envirotech, Delhi) that was attached with RDS to monitor the gaseous pollutants. For the determination of $SO_2$ and $NO_2$ gaseous pollutants, the monitoring was done at a constant flow rate of 1 l/min by bubbling ambient air through the liquid absorbing medium, however the proved modified Jacob and Hochheiser method (BIS, 2006a) with absorbing solution of sodium hydroxide and sodium arsenite was used for the determination of $NO_2$ and Improved West & Gaeke method with Potassium-tetrachloro-mercurate (K-TCM) as absorbing medium (BIS, 2001) was used to determine ambient $SO_2$ concentrations. For the determination of $NH_3$, the Indophenol method (CPCB, 2013) with absorbing solution of sulphuric acid along with phenol and sodium hypochlorite was used. The total PM monitoring was performed at an average flow rate of 1.2 $m^3$/min as prescribed in BIS, 2006b. Gaseous pollutants present in ambient air were absorbed in the respective absorbing medium and were analyzed spectrophotometrically at 560 nm, 540 nm and 630nm for $SO_2$, $NO_2$ and $NH_3$ respectively. The statistical analysis conducted with the data collected was carried out with the help of standardized statistical techniques.

In order to formulate association and comparison between pre-identified monitoring locations in respect of existing meteorological conditions, concentrations of air pollutants ($PM_{10}$, $PM_{2.5}$, $SO_2$, $NO_2$ and $NH_3$) i.e., from January, 2015 to December, 2015 were considered for analysis. The weather parameters for the study period (Jan-Dec, 2015) were persued from the regional meteorological station of IMD located at Lucknow in state of Uttar Pradesh. Statistical relationship between the monitored air quality parameters and meteorological variables were determined through regression analysis using Microsoft Excel Data Analysis Tool programme. Further, monthly average concentrations of air pollutants were analyzed in respect of meteorological factors to compute correlation coefficient.

For regression analysis, gaseous pollutants and particulate matter (PM) were considered as dependent variables, while meteorological parameters such as temperature (T), wind speed (WS), relative humidity (RH), evaporation and precipitation (P) were considered as independent variables, where relative humidity is taken as maximum and minimum relative humidity recorded during morning (830) and evening (1730) rush hours and wind speed is considered as morning (830) and evening (1730) rush hours separately. Pursuing the experiment, it was assumed that the dependent variables follow the normal distribution, homoscedasticity *i.e.*, the data have the equal variance and the difference between actual and theoretical values of dependent variables were independent (Íçaða and Sabah, 2009). It was also assumed that the meteorological parameters used in the multiple variable analyses were independent of each other. Linear regression analysis was performed to obtain the best probable prediction equation for the model chosen. This is mostly useful to predict the coefficient of the linear equation involving one or more independent variables which are useful to estimate the value of the dependent variable (Ilten and Selici, 2008). A general regression equation having four independent variables can be expressed as:

$$y=a+b_1x_1+b_2x_2+b_3x_3+b_4x_4$$

where *a* is the regression constant and *b*(n=1,2,3,4) is the regression coefficient. In order to minimize the error, the values of constant and coefficient are determined using the least-square method. The significance level of the constant and the coefficient were statistically tested using *t* and *F* distribution. The analysis of the direction, strength and statistical meaning of the variables were then computed to find out the determination of coefficient ($R^2$). The expected variance is the part of the variance of the predicted data which is explained by the regression line (Juda, 1986). The $R^2$ can be expressed as:

$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2}$$

where,

$\hat{y}_i$ = value of *y* predicted by the regression line

$y_i$ = value of *y* observed

$\bar{y}$ = mean of the s

Values of the coefficient of determination equalling to 1 ($R^2$ = 1) signify that the fitted equation accounts for all the variability of the dependent variables. In contrast to this, $R^2 = 0$ indicates the absence of any linear relationship between the pollutants and meteorological variables. It is considered that a high value of $R^2$ assures a statistically significant regression equation and vice-versa (Norusis, 1990)

## RESULTS AND DISCUSSION

**Correlation of air pollutants with meteorological variables**

Variability of air pollutant concentrations in a location with respect to a whole year has different individuality based on the prevalent meteorological conditions. Concentrations of air pollutants are subjected to change depending on the local climate and topography, source emissions and surrounding meteorological conditions over time. As meteorological factor differ considerably under varying geographical conditions, it is therefore, essential to study the existing statistical relations of meteorology on the variation of pollutant concentrations. To better understand the relation between different air pollutants, the correlation coefficients were found.

The correlation coefficient (r) between monthly average concentrations of $SO_2$, $NO_2$, $NH_3$, $PM_{2.5}$ and $PM_{10}$ with meteorological parameters has been shown in table 1, which discloses the statistically significant correlations. In the monitoring year 2015, all the air pollutants exhibit negative (-) correlations with maximum and minimum temperatures and rainfall, except $SO_2$ and $NO_2$ pollutants have positive (+) correlations with minimum temperature (0.025 and 0.082 respectively) and $PM_{2.5}$ have positive (+) correlations with rainfall (0.449). Wind speed and evaporation in identical with temperature and rainfall, all air pollutants exhibited negative (-) correlations in the range from -0.207 to -0.684, -0.073 to -0.736 and -0.230 to -0.806 respectively with the morning and evening hour wind speed and evaporation parameters. Existing correlations between air pollutants and maximum and minimum relative humidity were also found positive (+) within the range from 0.121 to 0.723 and 0.028 to 0.689 accordingly.

For the majority of the monitoring period, significant correlations were obtained in relation to maximum and minimum temperatures, followed by rainfall as the pollutant concentrations should decrease effectively with elevating temperatures and precipitation which can increase the possibility of enhanced wind circulation and simultaneously dilution of pollutants. Occurrence of negative correlations between air pollutants and meteorological variables insisted on the well established fact that rainfall acts as a wet scavenger of atmospheric pollutants (Panwar, 2014; Augustine, 2010). Computed correlations in respect to wind speed, relative humidity and evaporation revealed distinct results in terms of different months during the year. The effects of wind speed and direction on ambient air pollutant concentrations happens to be varied inversely as elevated wind speed dilutes the concentrations (Sharma and Pervez, 2002). In the present study, correlation between concentrations of gaseous pollutants and meteorological parameters revealed contrasting results with the findings of majority of earlier reports (Icaga and Sabah, 2009; Kumar *et al.*, 2011; Habeebullah, 2013; Chen *et al.*, 2015), though, it was well acknowledged that correlations results were somewhat differs in different related researches and might be subjected to variations depending upon the location and distinctive meteorological characteristics (Banerjee, 2010).

**Interpretation of regression analysis of air pollutants with meteorological parameters**

The relationship between $SO_2$, $NO_2$, $NH_3$, $PM_{2.5}$ and $PM_{10}$ and meteorological parameters was investigated by stepwise multiple linear regression analysis and for the year 2015, the outcome of regression analyses were illustrated in scatter plot diagram (Figure 1 - 5).

The results of the regression analysis revealed that all the air quality parameters documented a negative linear interactions with existing maximum temperature ($R^2$ = 4.9 – 73.5%), though the interaction of $NH_3$, $PM_{10}$ and $PM_{2.5}$ was found to be less significant with minimum temperature ($R^2$ = 18.7-35.3%), along with $SO_2$ and $NO_2$ pollutants depicting an positive interaction with temperature ($R^2$ = 0.1% and 0.7% respectively), explaining the fact that at low temperatures stable atmospheric conditions severely reduce the atmospheric dispersive capability and high temperatures help to disperse the pollution by causing turbulence. Contrasting results were also reported by Ocak and Turalioglu (2008), who founded that the moderate correlation occurs between NOx and temperature, where CO and NOx concentrations decrease with high increasing temperature, though $O_3$ concentration increase with increasing temperature.

A significant positive linear interactions between maximum and minimum relative humidity and all air pollutants were also found ($R^2$ = 1.4 – 52.3% and $R^2$ = 0.08 – 47.5%), where particulate matter seem to have less significant influence. Duenas *et al.* (2002) had reported that relative humidity plays an important role in air quality, either by affecting chain termination reactions or in the production of wet aerosols, which in turn affect the flux of ultraviolet radiation.

In addition, relative humidity is also well thought-out to be a limiting factor in the disposition of $NO_2$ because high percentages of humidity favour the reaction of the $NO_2$ with particles of sodium chloride salt (Duenas *et al.*, 2002) and

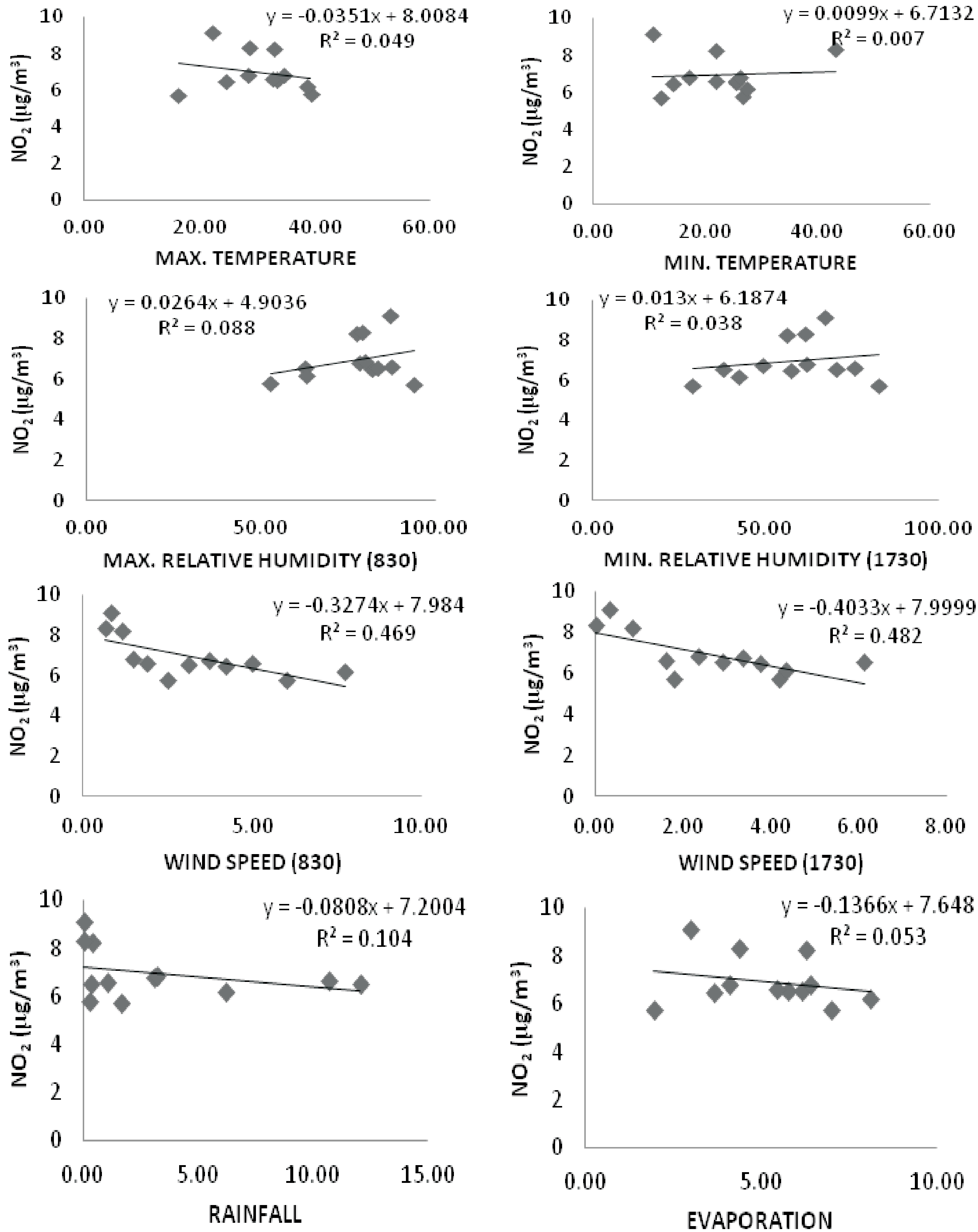


**Figure 2 : Interrelations between $NO_2$ and meteorological parameters in year 2015**

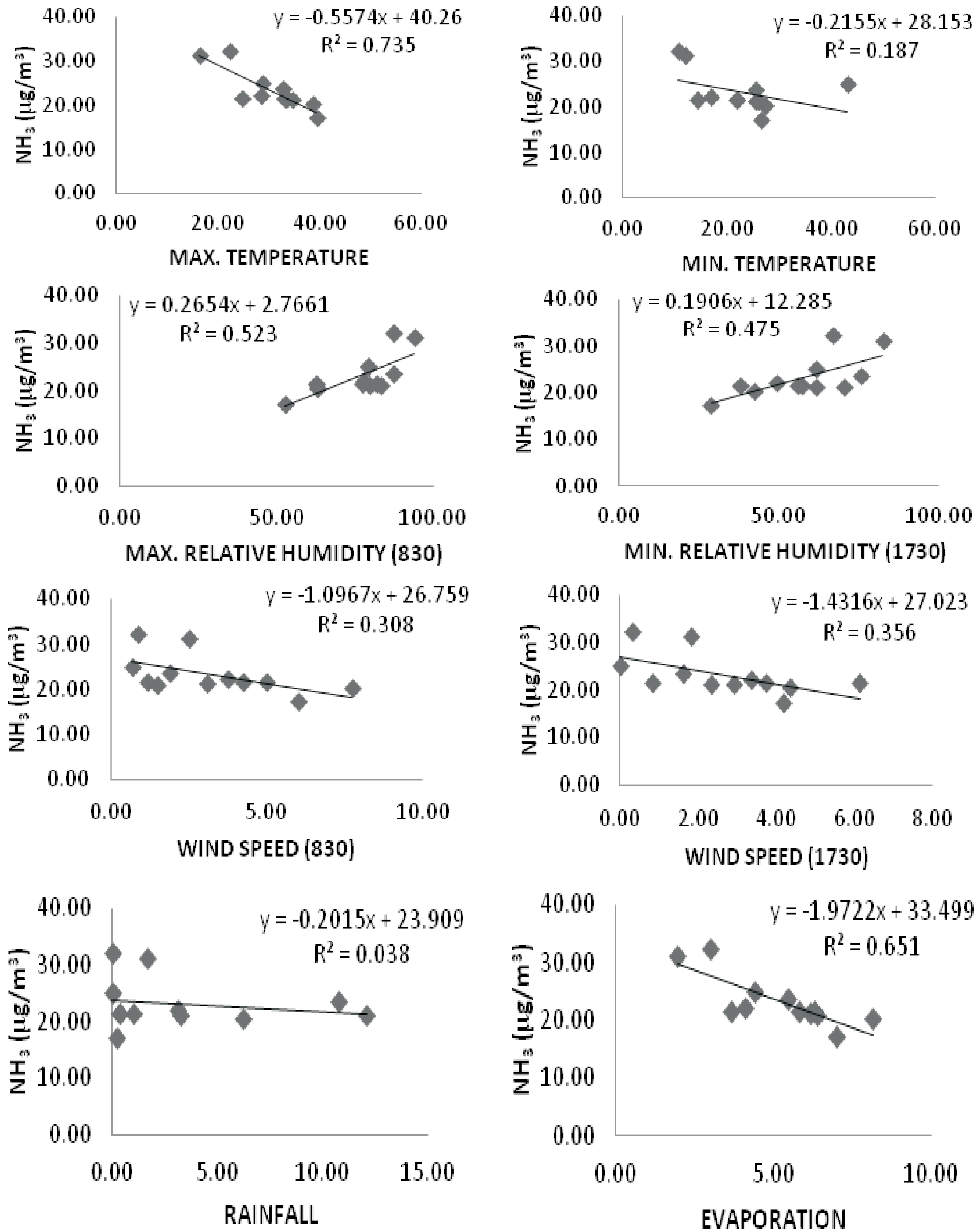


**Figure 3 : Interrelations between $NH_3$ and meteorological parameters in year 2015**

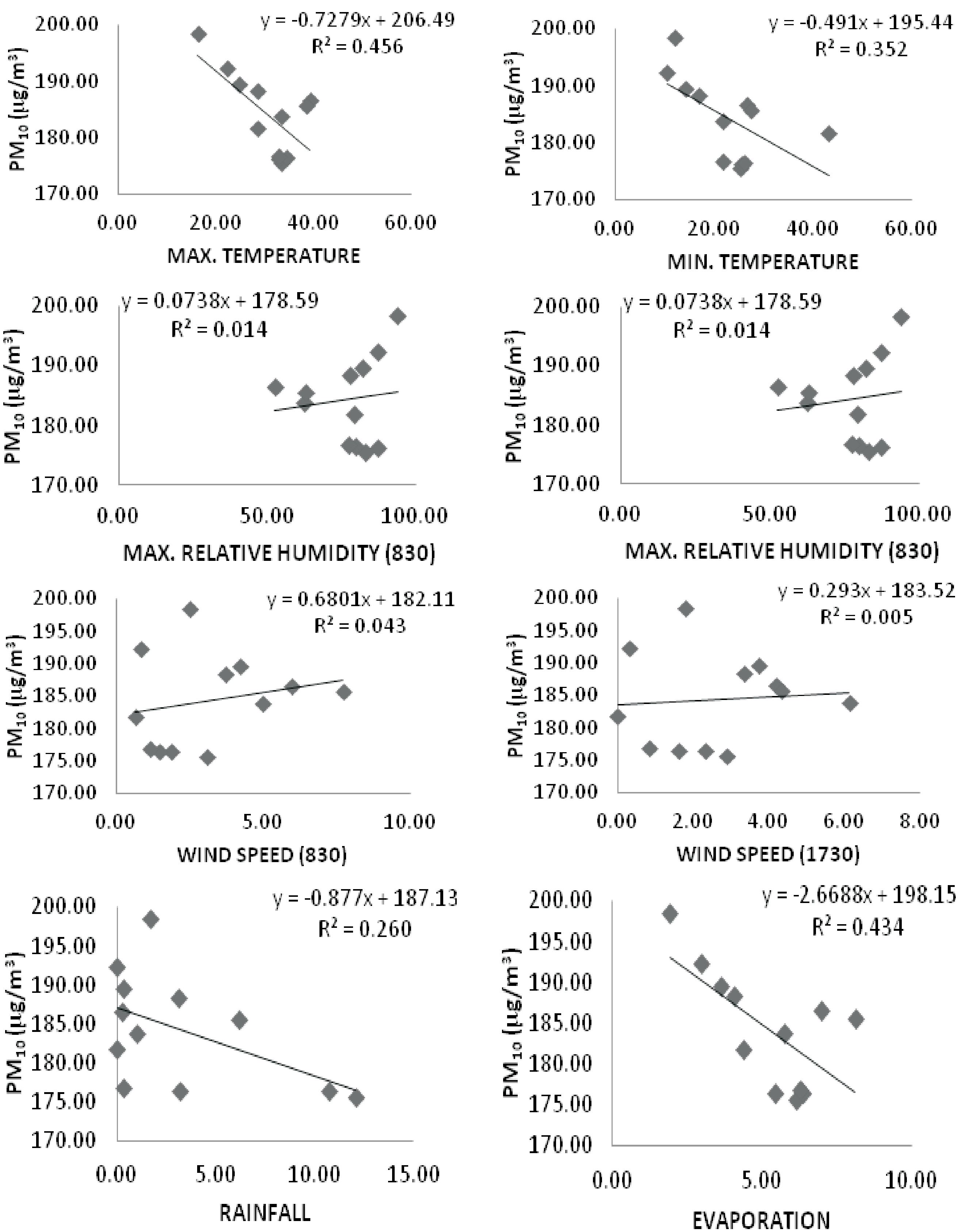


**Figure 4: Interrelations between $PM_{10}$ and meteorological parameters in year 2015**

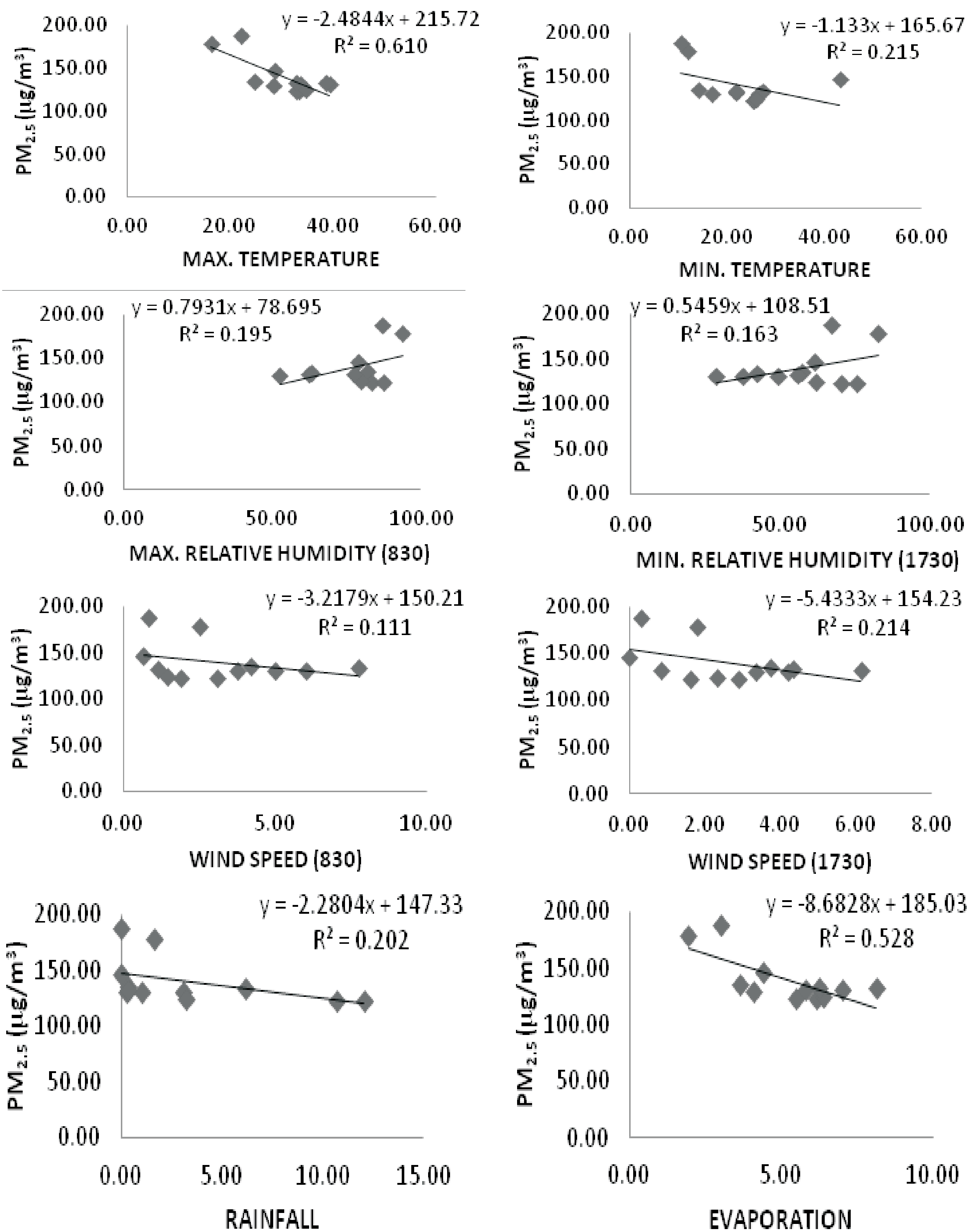


**Figure 5: Interrelations between $PM_{2.5}$ and meteorological parameters in year 2015**

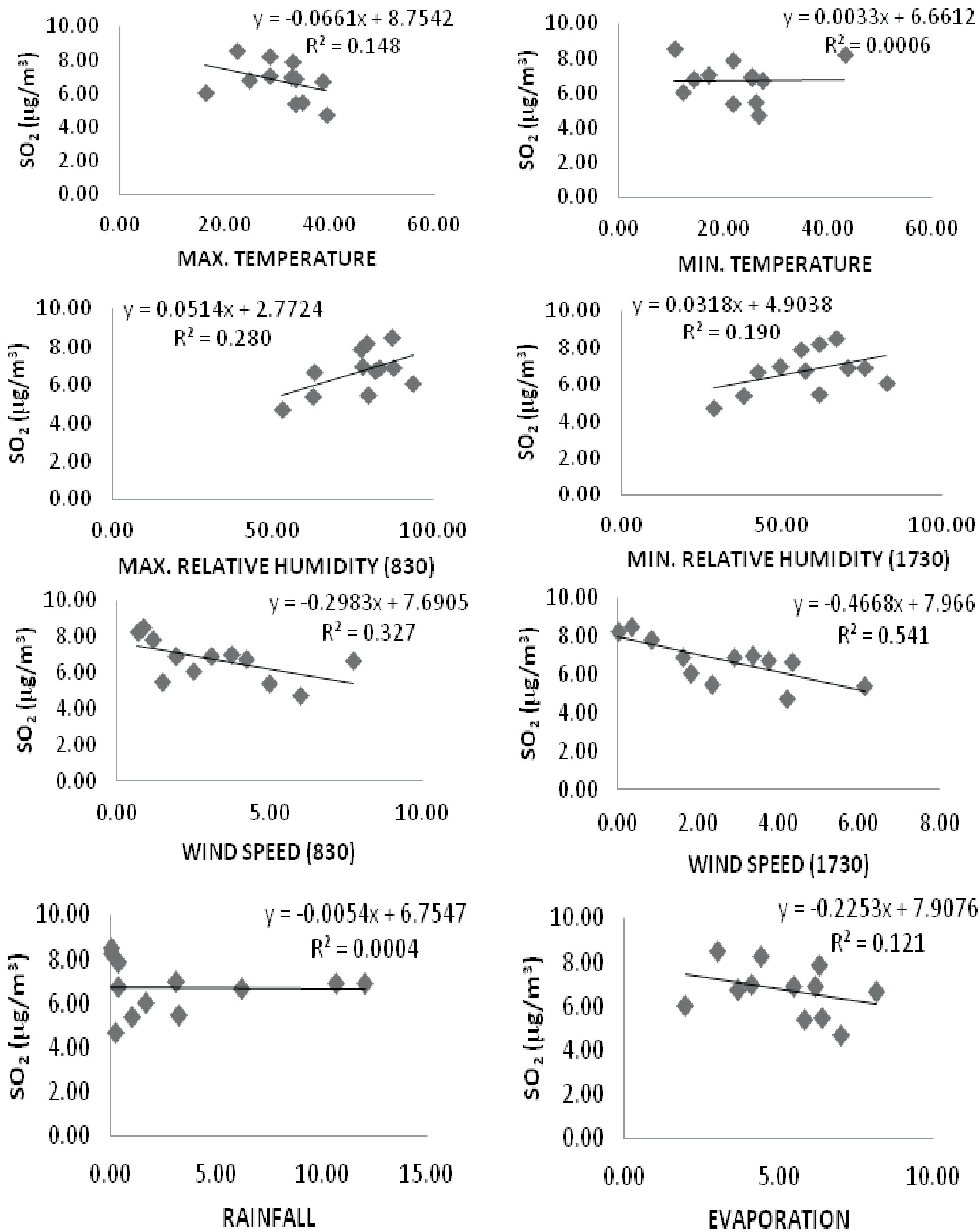


**Figure 1 : Interrelations between $SO_2$ and meteorological parameters in year 2015**

**Table 1 : Computed correlation coefficient (*r*) between meteorological parameters and air pollutants during the study period**

| 2015 | Max. Temp. | Min. Temp. | Max. RH | Min. RH | Rainfall | Wind speed -830 | Wind speed -1730 | Evapo-ration |
|---|---|---|---|---|---|---|---|---|
| $SO_2$ | -0.384* | 0.025 | 0.529 | 0.436 | -0.019 | -0.571* | -0.736** | -0.348 |
| $NO_2$ | -0.222 | 0.082 | 0.296 | 0.194 | -0.321 | -0.684** | -0.694** | -0.23 |
| $NH_3$ | -0.857** | -0.431 | 0.723** | 0.689** | -0.194 | -0.555 | -0.596* | -0.806** |
| $PM_{10}$ | -0.675** | -0.594* | 0.121 | 0.028 | -0.51 | -0.207 | -0.073 | -0.659** |
| $PM_{2.5}$ | -0.781** | -0.464 | 0.442 | 0.403 | 0.449 | -0.333 | -0.462 | -0.726** |

Note :* = significant at 5% level;** = significant at 1% level

may also act on air pollutants to create secondary aerosols, like sulphate and nitrate ions, which contribute positively to $PM_{10}$ concentrations.

Jayamurugan *et al.*(2013) analysed the influence of temperature and relative humidity on ambient $SO_2$, NOx, RSPM, and SPM concentrations at North Chennai, India, during 2010-11 using regression analysis and showed that statistically significant negative correlations were found between humidity and particulates in all the four seasons, but level of correlation was found moderate only during monsoon (r1= 0.51 and r2= 0.41) in comparison with other three seasons and no significant correlation was found between humidity and $SO_2$, NOx in all the seasons, suggesting that the influence of humidity is effective on subsiding particulates in the coastal region.

For all the concerned cases, the morning and evening hour wind speed ($R^2$ = 4.3 – 46.9% and 21.4 – 54.2%) and evaporation ($R^2$ = 5.3 - 65.1%) were believed to persist considerably good linear interaction with all the air pollutants, indicating that the concentrations of pollutants tends to get diluted with increasing wind speed but may be elevated as the speed of wind decreases (Aneja *et al.*, 2001; Alkatheeri *et al.*, 2012). On the other hand, the levels of interactions ($R^2$ = 0.04 – 26.0%) were also lower for precipitation with all pollutants exhibiting the negative relations.

Though, it is seen from figure 1-5 that correlations of air pollutants for temperature, rainfall, evaporation, wind speed and relative humidity obtained at this study were contrasting to those findings reported at other studies. Giri *et al.* (2008) had studied the relationship between meteorological process and air pollution in Kathmandu in Nepal and found that the increase of rainfall and humidity has negative correlation with concentration of particulate matter. The study also infers that the wind speed and atmospheric pressure inducing increment of average $PM_{10}$ concentration in Kathmandu Valley. Dominick *et al.* (2012) considered the influence of meteorological parameters (temperature, relative humidity, and wind speed) on a daily average estimation of $PM_{10}$ and $NO_2$ at three selected stations in Malaysia and found that the temperature has a positive correlation to the concentration of $PM_{10}$ but a negative correlation to relative humidity for all three stations, however, Hargreaves *et al.* (2000) reported a weak negative association between $NO_2$ concentration and wind speed. Giakoumi *et al.* (2009) indicated a considerable relation of climatic variables with suspended particles and nitrogen oxide in Athens, Greece. Chiu *et al.* (2005) investigated the local meteorological parameters such as solar radiation, wind speed and wind direction effects on $O_3$, $NO_2$ concentration and founded a positive correlation between ozone levels and solar radiation during daytime, increasing level of ozone with increased radiation.

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